Analysis of Weaving, Merging, and Diverging Movements
CIVL 4162/6162
Weaving, Diverging, Merging Segments

• Weaving - one movement must cross the path of another along a length of facility without the aid of signals or other traffic control devices

• Merging - two separate traffic streams join to form a single one

• Diverging - one traffic stream separates to form two separate traffic streams

• Why do we consider these separately from BFS/Multilane Segments?
Figure 15.1 Weaving, Merging, and Diverging Movements Illustrated

(a) Weaving movements cross each others path.

(b) Merging movements join to form a single traffic stream.

(c) Diverging movements divide to form separate traffic streams.
# LOS for W/M/D Segments

## Table 15.1: Level-of-Service Criteria for Weaving, Merging, and Diverging Segments

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<th>Weaving Areas</th>
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Flows in a Weaving Segment and the Weaving Diagram
Weaving Configurations

(a) One-Sided Ramp-Weave

(b) One-Sided Major Weave

(c) Two-Sided Weaving Segment w/ Single-Lane Raps

(d) Two-Sided Weaving Segment w/ Three Lane Changes
Weaving Configuration Parameters

(a) A Five-Lane Ramp-Weave Section

(b) A Four-Lane Major Weave Section
(No Lane Balance)

(c) A Four-Lane Major Weave Section
(With Lane Balance)
Figure 15.2 Influence Areas for Merge, Diverge, and Weaving Segments (Source: Used with permission of Transportation Research Board, National Research Council, modified from *Highway Capacity Manual*, 2000, Exhibit 13-13, p. 13-21.)
Weaving Analysis - Input Requirements

- Existing roadway and traffic conditions are required, including:
  - Length and width of weaving area
  - Number of lanes
  - Type of configuration
  - Terrain/grade conditions
  - FFS
  - Hourly volumes
Step 1: Input Data
Specify geometry, weaving and nonweaving volumes, and the segment’s free-flow speed.

Step 2: Adjust Volume
Adjust demand volumes to reflect the peak hour factor, heavy-vehicle presence, and driver population (Equation 12-1).

Step 3: Determine Configuration Characteristics
Determine the lane-change characteristics that define the effects of configuration.

Step 4: Determine Maximum Weaving Length
Estimate the maximum length for weaving operations under the specified conditions (Equation 12-4).

Step 5: Determine Weaving Segment Capacity
Estimate the weaving segment capacity and the v/c ratio for the existing or projected demand flow rates (Equations 12-5 through 12-9).

- v/c ≤ 1.00
  - Level of Service = LOS F
- v/c > 1.00
  - Go to Chapter 13

Step 6: Determine Lane-Changing Rates
Estimate the rate at which weaving and nonweaving vehicles make lane changes (Equations 12-10 through 12-16).

Step 7: Determine Average Speeds of Weaving and Nonweaving Vehicles
Estimate the average speed of weaving and nonweaving vehicles in the weaving segment; compute the space mean speed of all vehicles in the weaving segment (Equations 12-17 through 12-20).

Step 8: Determine LOS
Convert the space mean speed to the weaving segment density. Compare the results to the LOS criteria and assign the appropriate level of service (Equation 12-21 and Exhibit 12-10).
Symbol Definition

- $v_{FF}$: freeway-to-freeway demand flow rate in the weaving section (pc/h)
- $v_{RF}$: ramp-to-freeway demand flow rate in the weaving section (pc/h)
- $v_{FR}$: freeway-to-ramp demand flow rate in the weaving section (pc/h)
- $v_{RR}$: ramp-to-ramp demand flow rate in the weaving section (pc/h)
- $v_W$: weaving demand flow rate in the weaving section (pc/h): $v_W = v_{RF} + v_{FR}$
- $v_{NW}$: non-weaving demand flow rate in the weaving section (pc/h): $v_{NW} = v_{FF} + v_{RR}$
- $v$: total demand flow rate in the weaving section (pc/h), $v = v_W + v_{NW}$
- $VR$: volume ratio: $VR = v_W/v$
- $N$: number of lanes within the weaving section
- $N_W$: number of lanes from which a weaving maneuver may be made with one or no lane changes.
- $S_W$: average speed of weaving vehicles within the weaving section (mi/h)
- $S_{NW}$: average speed of non-weaving vehicles within the weaving section (mi/h)
- $S$: average speed of all vehicles within the weaving section (mi/h)
- $FFS$: free-flow speed of the weaving section (mi/h)
Figure 15.8 (continued)  Weaving Variables Defined for One-Sided Weaving Segments *(Source: Roess, R., et al., Analysis of Freeway Weaving Sections, Final Report, Draft Chapter for the HCM, National Cooperative Highway Research Program Project 3-75, Polytechnic University and Kittelson and Associates, Brooklyn, NY, September 2007, Exhibit 24-7, p. 12.)*

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
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<tbody>
<tr>
<td>D</td>
<td>average density of all vehicles within the weaving section (pc/mi/ln)</td>
</tr>
<tr>
<td>W</td>
<td>weaving intensity factor</td>
</tr>
<tr>
<td>L&lt;sub&gt;S&lt;/sub&gt;</td>
<td>length of the weaving section (ft), based on short length definition.</td>
</tr>
<tr>
<td>L&lt;sub&gt;RF&lt;/sub&gt;</td>
<td>minimum number of lane changes that must be made by a single weaving vehicle moving from the on-ramp to the facility.</td>
</tr>
<tr>
<td>L&lt;sub&gt;FR&lt;/sub&gt;</td>
<td>minimum number of lane changes that must be made by a single weaving vehicle moving from the facility to the ramp.</td>
</tr>
<tr>
<td>L&lt;sub&gt;MIN&lt;/sub&gt;</td>
<td>minimum rate of lane changing that must exist for all weaving vehicles to successfully complete their weaving maneuvers (lc/h) ( LC_{MIN} = (LC_{RF} \times v_{RF}) + (LC_{FR} \times v_{FR}) )</td>
</tr>
<tr>
<td>L&lt;sub&gt;W&lt;/sub&gt;</td>
<td>total rate of lane changing by weaving vehicles within the weaving section (lc/h)</td>
</tr>
<tr>
<td>L&lt;sub&gt;NW&lt;/sub&gt;</td>
<td>total rate of lane changing by non-weaving vehicles within the weaving section (lc/h)</td>
</tr>
<tr>
<td>L&lt;sub&gt;ALL&lt;/sub&gt;</td>
<td>total lane-changing rate of all vehicles within the weaving section (lc/h) ( LC_{ALL} = LC_{W} + LC_{NW} )</td>
</tr>
</tbody>
</table>
Step-1: Input Data

• Ensure to write all the input data in one place before analyzing the weaving section
Step-2: Determining Flow Rate

\[ v_i = \frac{V_i}{PHF \times N \times f_{HV} \times f_p} \]

- \( v_i \): Demand flow rate, pc/h, under equivalent based conditions
- \( V_i \): Demand volume, veh/hr under prevailing conditions
- \( PHF \): Peak Hour Factor
- \( f_{HV} \): Heavy-vehicle adjustment factor
- \( f_p \): Driver-population adjustment factor
Figure 15.3  Flows in a Weaving Segment and the Weaving Diagram

\[ v_{o1} \]: larger outer flow
\[ v_{o2} \]: smaller outer flow
\[ v_{w1} \]: larger weaving flow
\[ v_{w2} \]: smaller weaving flow
\[ v_w \]: Total weaving = \[ v_{w1} + v_{w2} \]
\[ v_{nw} \]: Total non-weaving = \[ v_{o1} + v_{o2} \]
\[ V \]: Total Demand = \[ v_w + v_{nw} \]
\[ VR \]: Volume Ratio = \[ \frac{v_w}{V} \]
\[ R \]: Weaving Ratio = \[ \frac{v_{w2}}{v_w} \]
Step-3: Determine Configuration Characteristics

- **One Sided Weaving**
  - \( \text{LC}_{RF} \) - minimum # of lane changes that a ramp-to-facility weaving vehicle must make to successfully complete the ramp-to-facility movement.
  - \( \text{LC}_{FR} \) - minimum # of lane changes that a facility-to-ramp weaving vehicle must make to successfully complete the facility-to-ramp movement.
  - \( N_{WV} \) - number of lanes from which a weaving maneuver may be completed with one lane change, or no lane change.

\[
\text{LC}_{MIN} = (\text{LC}_{FR} \quad \text{FR}) + (\text{LC}_{RF} \quad \text{RF})
\]
Step-3: Determine Configuration Characteristics

- Two Sided Weaving
  - \( L_{RR} \) - minimum number of lane changes required for ‘ramp-to-ramp’ movement.
  - \( N_{wv} = 0 \) (only vehicles moving ramp to ramp are considered to be weaving)

\[
LC_{MIN} = \left( L_{CR} \quad RR \right)
\]

Symbol Definition

- \( v_W \) total weaving demand flow rate within the weaving section (pc/h) \( v_W = v_{RR} \)
- \( v_{NW} \) total non-weaving demand flow rate within the weaving section (pc/h) \( v_{NW} = v_{FR} + v_{RF} + v_{FF} \)
- \( LC_{RR} \) minimum number of lane changes that must be made by one ramp-to-ramp vehicle to complete a weaving maneuver.
- \( LC_{MIN} \) minimum rate of lane changing that must exist for all weaving vehicles to successfully complete their weaving maneuvers (lc/h) \( LC_{MIN} = (LC_{RR} \times v_{RR}) \)
Figure 15.8  Weaving Variables Defined for One-Sided Weaving Segments (Source: Roess, R., et al., Analysis of Freeway Weaving Sections, Final Report, Draft Chapter for the HCM, National Cooperative Highway Research Program Project 3-75, Polytechnic University and Kittelson and Associates, Brooklyn, NY, September 2007, Exhibit 24-7, p. 12.)
Figure 15.9  Weaving Variables Defined for Two-Sided Weaving Segments (Source: Roess, R., et al., Analysis of Freeway Weaving Sections, Final Report, Draft Chapter for the HCM, National Cooperative Highway Research Program Project 3-75, Polytechnic University and Kittelson and Associates, Brooklyn, NY, September 2007, Exhibit 24-8, p. 13.)
Step-4: Maximum Weaving Length

\[ L_{MAX} = \left[ 5,728(1 + VR)^{1.6} \right] 1,566N_{VW} \]

Figure 15.6 Measuring the Length of a Weaving Segment (Source: Roess, R., et al., Analysis of Freeway Weaving Sections, Final Report, Draft Chapter for the HCM, National Cooperative Highway Research Program Project 3-75, Polytechnic University and Kittelson and Associates, Brooklyn, NY, September 2007, Exhibit 24-2, p. 2.)
Step-5: Capacity of the Weaving Segment

- Based on Breakdown Density

Calculate $C_{IWL}$ (cap per lane of weaving section under ideal conditions):

$$c_{IWL} = c_{IFL} \left[ 438.2(1+VR)^{1.6} \right] + \left[ 0.0765L_S \right] + \left[ 119.8N_{WV} \right]$$

Convert $C_{IWL}$ to total capacity for the weaving segment under prevailing conditions:

$$c_{W1} = c_{IWL} \times N \times f_{HV} \times f_p$$
# Capacity Values - $C_{IFL}$

**Table 15.2:** Basic Facility Capacity Values ($c_{IFL}$) for Use in Equation 15-5

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<thead>
<tr>
<th>Freeways</th>
<th>Multilane Highways and C–D Roadways</th>
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<tbody>
<tr>
<td>FFS (mi/h)</td>
<td>Capacity (pc/h/ln)</td>
</tr>
<tr>
<td>$\geq 70$</td>
<td>2,400</td>
</tr>
<tr>
<td>65</td>
<td>2,350</td>
</tr>
<tr>
<td>60</td>
<td>2,300</td>
</tr>
<tr>
<td>55</td>
<td>2,250</td>
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Step-5: Capacity of the Weaving Segment

- **Based on Maximum Weaving Flow Rate**

  Calculate $C_{IW}$ (based on # weaving lanes):

  $c_{IW} = \frac{2,400}{VR}$ for $N_{WL} = 2$ lanes

  $c_{IW} = \frac{3,500}{VR}$ for $N_{WL} = 3$ lanes

  Convert $C_{IW}$ to total capacity for the weaving segment under prevailing conditions:

  $c_{W2} = c_{IW} \times f_{HV} \times f_p$

- **Final Capacity and v/C ratio**

  $c_w = \text{Min} \ (c_{w1}, \ c_{w2})$

  $\frac{v}{c} = \frac{v f_{HV} f_p}{c_w}$

  If $v/c > 1.0$, LOS = F, and STOP
Step-6: Total Lane Changing

- For Weaving Vehicles
  Total lane changing rate for weaving vehicles

  \[ LC_W = LC_{MIN} + 0.39[(L_S - 300)^{0.5}N^2(1 + ID)^{0.8}] \]

- For Non-Weaving Vehicles

  \[ LC_{NW1} = 0.206v_{NW} + 0.542L_S - (192.6N) \]

  \[ LC_{NW2} = 2135 + 0.223(v_{NW} - 2000) \]
Step-6: Total Lane Changing

- **Lane Changing Index**
  Total lane changing rate for weaving vehicles

  \[ I_{NW} = \frac{L_{SID} v_{NW}}{10,000} \]

- **I\textsubscript{NW} Ranges**
  - If \( I_{NW} < 1,300 \)
    \( \text{LC}_{NW} = \text{LC}_{NW1} \)
  - If \( I_{NW} > 1,950 \)
    \( \text{LC}_{NW} = \text{LC}_{NW2} \)
  - If \( 1300 < I_{NW} < 1,950 \)
    \[ \text{LC}_{NW} = \text{LC}_{NW1} + (\text{LC}_{NW2} - \text{LC}_{NW1}) \left( \frac{I_{NW} - 1300}{650} \right) \]

- **Total Lane Changing**

  \[ \text{LC}_{ALL} = \text{LC}_{NW1} + \text{LC}_{NW2} \]
Step-7: Average Speed

- **Weaving Vehicles**

\[ S_W = S_{MIN} + \left( \frac{S_{MAX} - S_{MIN}}{1 + W} \right) \]

\[ W = 0.226 \left( \frac{LC_{ALL}}{L_S} \right)^{0.789} \]

\[ S_W = 15 + \left( \frac{FFS - 15}{1 + W} \right) \]

- **Non-Weaving Vehicles**

\[ S_{NW} = FFS - (0.0072LC_{MIN}) + (0.0048v/N) \]

- **Average Speed**

\[ S = \frac{\frac{v_W}{S_W} + \frac{v_{NW}}{S_{NW}}}{\frac{1}{S_W} + \frac{1}{S_{NW}}} \]
Step-8: Determine Density

\[ D = \frac{\left( \frac{V}{N} \right)}{S} \]

where \( D \) is the average density for all vehicles in the weaving segment (pc/mi/ln).
## LOS for W/M/D Segments

### Table 15.1: Level-of-Service Criteria for Weaving, Merging, and Diverging Segments

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Example

What are the level of service and capacity of the weaving segment on the urban freeway shown below?  ID = 0.8 int./mi - 10 percent trucks; PHF=0.91; level terrain; fp=1, FFS=65 mph

\[ L_S = 1,500 \text{ ft} \]

\[ \nu_{FF} = 1,815 \text{ veh/h} \]
\[ \nu_{RF} = 1,037 \text{ veh/h} \]
\[ \nu_{FR} = 692 \text{ veh/h} \]
\[ \nu_{RR} = 1,297 \text{ veh/h} \]

\[ \nu = 4,841 \text{ veh/h} \]
Example

- A typical ramp weave section on a six lane freeway (three lanes in each direction). Determine LOS under prevailing conditions.